EVALUATION OF THE DIRECT VIEW STORAGE DISPLAY FOR SIGNAL ANALYSIS

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NAVAL POSTGRADUATE SCHOOL

Monterey, California

THESIS

EVALUATION OF
THE DIRECT VIEW STORAGE
DISPLAY FOR SIGNAL ANALYSIS

by

William Alvin Fuson

March, 1976

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The visual processing of received radio and acoustic frequency spectrum data by human analysts forms an important portion of our current defense efforts. Both of these areas present many of the same basic problems to the analyst. These problems center on discovering the most effective means of presenting the data to a human observer for investigation. Currently the prevalent analysis medium for acoustic data is the

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lofargram, figure 1.

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Evaluation of
the Direct View Storage Display
for Signal Analysis

by

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ABSTRACT

The visual processing of received radio and acoustic frequency spectrum data by human analysts forms an important portion of our current defense efforts. Both of these areas present many of the same basic problems to the analyst. These problems center on discovering the most effective means of presenting the data to a human observer for investigation. Currently the prevalent analysis medium for acoustic data is the lofargram, figure 1.

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TABLE OF CONTENTS

LIST OF FIGURES

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I. INTRODUCTION

The basic motivation for the work described in this thesis was to evaluate a direct view storage tube (DVST) type of display terminal in a signal processing environment. However, before this evaluation could be accomplished, new software tailored to meet the special requirements created by the DVST was necessary. These special requirements are necessitated by the method employed to eliminate the refresh requirements from the display. In order to eliminate the need for refresh the DVST utilizes two electron guns (a flood cathode and a writing cathode) to initially display and then to maintain an image. In addition to the two cathodes there is also a negatively charged collector and a storage grid which serve key functions in the display.

In order to provide the stored image the writing cathode provides a high speed electron beam which places the desired image on the storage grid in the form of a line or lines of positive charge. At this point the actual writing is accomplished by the flood cathode which provides a relatively low speed, diffused electron field. This flood of electrons is then more evenly diffused by the collector in an attempt to provide an even flow to the storage grid. The positive charges placed on the storage grid by the writing cathode will then attract the

low speed electrons from the collector and send them on to the screen for actual image illumination. The remaining flood electrons are of such low velocity that they cannot penetrate the storage grid, and thus provide no screen illumination. However, over enough time positive charge will be deposited on the storage grid so as to begin allowing some of the low speed flood electrons to begin penetrating and providing general screen illumination. Thus giving rise to a problem called fogging, which results when the background brightness of the image increases sufficiently to be detected. This does not become a problem until such time as it decreases the contrast between the stored image and its background to the point where the user has difficulty distinguishing the stored image.

The original concept of the SPOTLIGHT program was very well received by the personnel who would be the end users of such a system. Those who tried the system on actual real-world data were impressed by the physical display format and the ease with which it could be manipulated to suit the immediate needs of the user. These impressions were of such significance that spotlighting has become part of the vocabularly in acoustic analysis. Of equal importance was the result that the combination of display format and the interaction capabilities with which the user was provided combined for an effective, accurate and more human oriented method of data analysis than the

current lofargram method. These results alone provided the necessary incentive to investigate the possibilities of reducing the size and cost of equipment to a point where implementation of the SPOTLIGHT concept would be practical on a large scale basis. The popularity of SPOTLIGHT demanded a serious attempt to implement it using the inexpensive DVST display and a small mini-computer comparable to the Navy's AN/YUK-20 computer.

Of particular interest at this point is the application of one or more mini-computers to a small general purpose cathode ray tube (CRT) display medium. The benefits here would be many and among the most significant are the small physical size, low initial costs, low environmental requirements, greater reliablilty and low maintenance requirements (both for hardware and software). The equipment of immediate concern was the use of an AN/UYK-20 series mini-computer as the processor and a TEKTRONIX/4014 - 1 display as the primary user interface. Although initial plans called for testing the AN/UYK-20 along with the TEKTRONIX, the AN/UYK-20 proved unavailable for inclusion in the work leading up to this thesis. It was due to this restriction that the programming effort was devoted entirely to the PDP-11/50 environment. Thus, the purpose became one of deriving the actual performance capabilities of the storage display as well as the levels of performance required of a processor and associated hardware in order to acheive these performance levels. The

additional hardware of particular concern here were items such as the actual interfaces and peripheral storage items needed for optimum performance.

Once the requirements for the processor side of the problem had been determined, the primary task became the determination of the actual capabilities and limitations of the display. The analysis needed to discover not only the maximum drawing speeds of the terminal but also how well an analyst could utilize a storage tube type of display in the dynamic signal processing environment.

While evaluating the display's usefulness, it was necessary to keep several key points under immediate and constant consideration. First and probably the single most important feature, was maintaining the accuracy of display. Secondly, to maintain a system which is user oriented. The level of interactive capabilities and the user implementation of them must be as effective as possible. The display format was to remain as nearly identical to that of the SPOTLIGHT system as possible, as was the basic command structure. The primary reason for this aim was that during SPOTLIGHT system evaluation, the personnel involved made no consistant or re-occurring recommendations for major changes which had not already been implemented. The last major area of concern was that the program size was to be kept as small and logically simple as possible, while still obtaining the desired results. These restrictions were necessary since without regard to

the terminal's performance, if the program required to accomplish it were large and extremely complex then its use on a mini-computer such as the AN/UYK-20 might be in doubt. A doubt resulting primarily from the limited memory and peripheral resource avabilities which prevail in the AN/UYK-20 system at present.

II. THE PROBLEM

As previously mentioned one of the primary means of displaying acoustic frequency spectrum data for analysis in the Navy is the lofargram. The basis of data display for a lofargram is a line of varying intensity drawn on a sensitized paper (usually heat sensitive) representing a given frequency spectrum at the rate of one line per time increment. As the pen draws this line, its intensity varies directly with the amplitude of the signal. The lofargram presents the analyst with a line of multiple intensities for each time increment, reference figure 1.

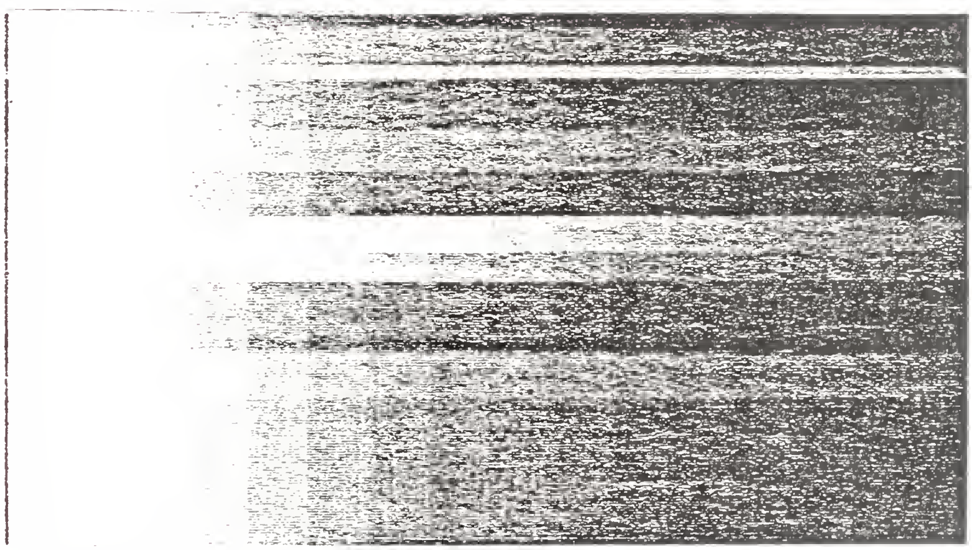


figure 1: the lofargram medium

This presentatioin provides no physical distinction between the intensities other than the shade differences

themselves. It is at this point that the observer initially encounters difficulity in the analysis problem, since the human's ability to detect differences in shades of grey is one of his weakest sensory capabilities. In order to detect a predominant or consistent signal trend, a deviation in line intensity must be initially detected and then observed for several time increments in order to be a reliable detection.

If the signal to be detected represents only a slight increase in amplitude over the surrounding noise levels, then the intensity change in the frequency line may be relatively slight (if at all). The degree to which this is a factor depends on the fact that a particular gram writer will have a set number of available intensity levels, or shades of gray, with which to represent the various signal amplitudes. Thus, given only a slight signal amplitude change, the intensity shift associated with it may consist of only a one level change and as a result may go totally unnoticed until a further shift occurs. This poses a difficult problem since the longer an analyst views the grams the lower his ability to detect the more minor shifts in intensity, and thus his useful time is limited. Therefore, it is of relative importance to find a system of presenting data which will prolong the observer's useful time, as well as increase his ability to detect the more minor

changes in data flow.

A reasonable alternative to the gram approach was the use of a standard x-y coordinate plane graph where the vertical axis represents signal amplitude and the horizontal represents the frequency spectrum under consideration, reference figure 2.

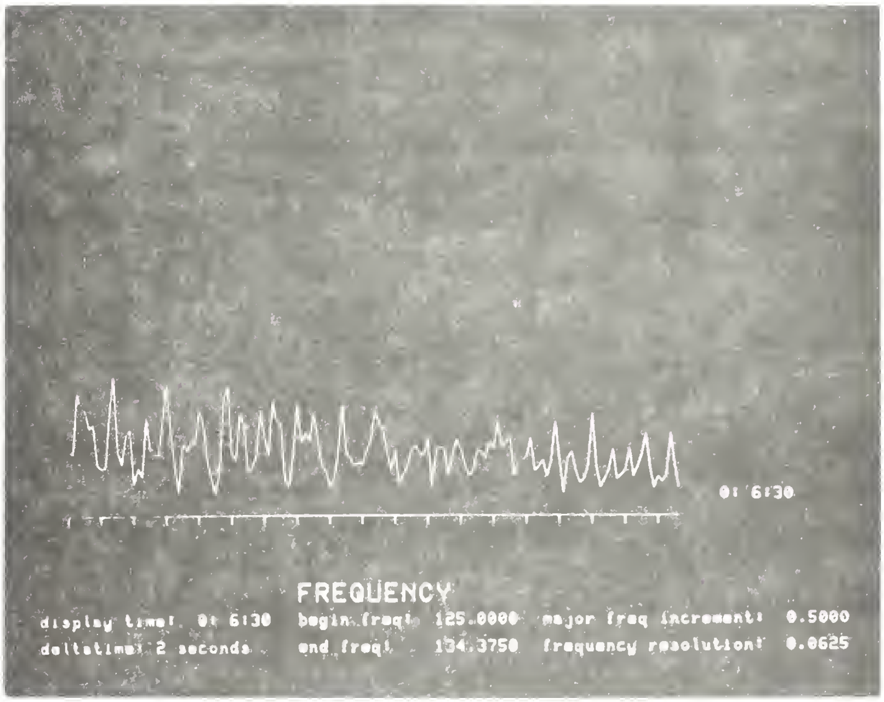


figure 2: Amplitude versus frequency diagram.

The presentation of a single display line to the user would provide little analysis capability to detect minor changes in the data flow. Consequently, a third dimension

was implemented into the display to provide a sense of time for the user. The time reference was then used to present the most current data first on the time axis and the previous ones behind it. A pictorial representation of this concept, known as a waterfall presentation, is provided in figure 3.

The waterfall display provides the analyst with a specified number of data lines for analysis which are represented as x-y coordinate graphs. Therefore, the data analyst was simply waiting for a line to appear which illustrated physical inconsistencies or new trends as compared to the previous lines, not intensitity differences. The result of this approach was, as mentioned earlier, well received and is still being developed.

The problem addressed by this thesis is to take the current solution to the acoustic data analysis problem and attempt to utilize newer, smaller and less expensive hardware to realize the desired result. It is precisely this problem which will be addressed formally and the discussions will be based on work accomplished on the TEKTRONIX 4014-1 display terminal as it was applied to a dynamic processing and display situation. The problem here is not so much to design a display but to take an existing format and mold it to a different type of implementation and evaluate the results.

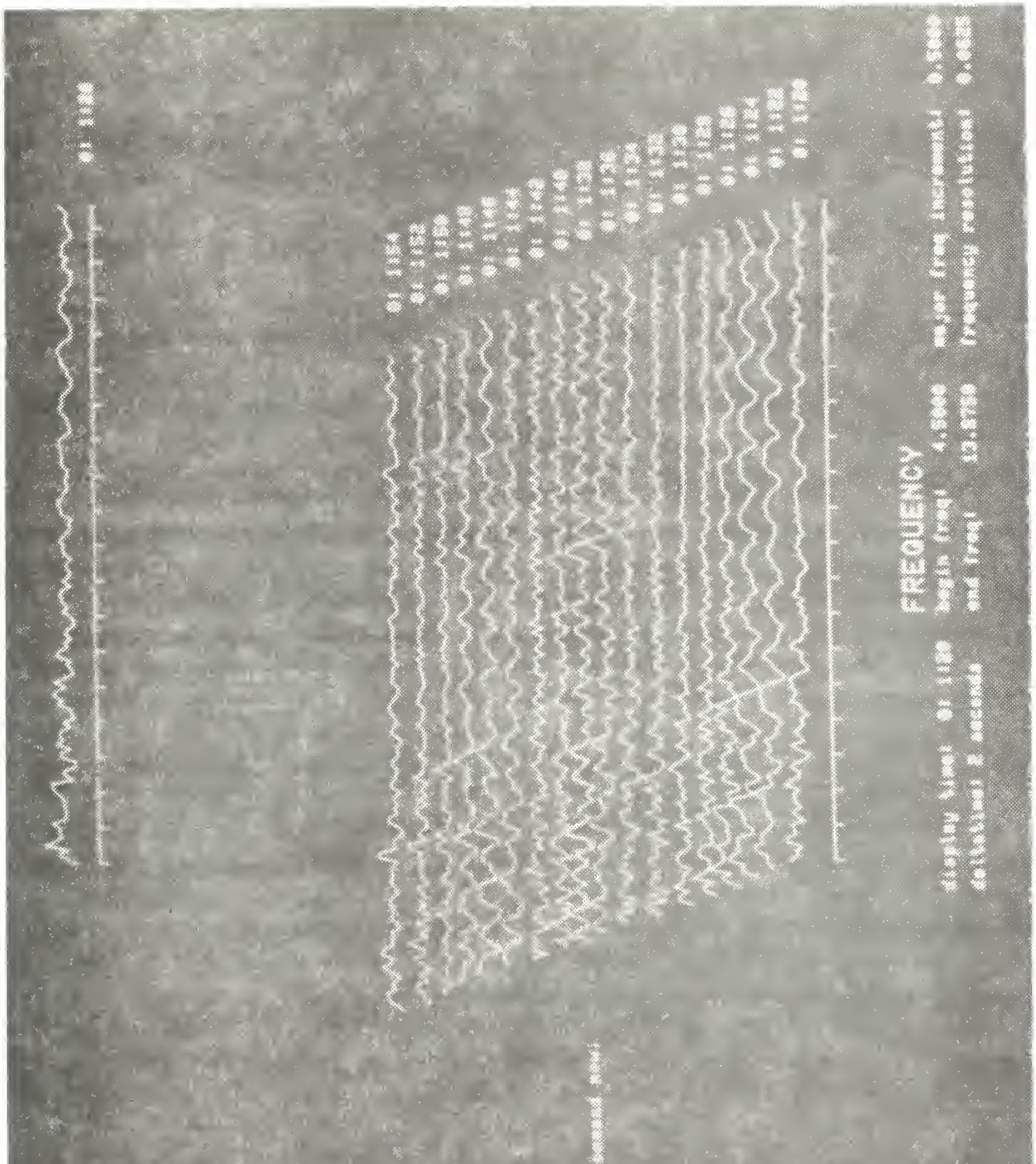


figure 3: The waterfall display concept

The major area of interest was the effects of using storage tube technology as a replacement for the more expensive refresh vector-drawing implementation in this area. Principle concerns were the lack of selective erasure and the effect on the user of the flash of light normally associated with the erasing of a storage display. Also a point of interest was to discover if the problems of "fogging" which were so prevalent on previous storage tube units is still a problem and if so, would it affect this particular application.

Yet another characteristic of storage tube displays was a problem relating to the vector drawing speeds associated with the system. The major influence here is the time required to build up to the intensity levels necessary to create a stored image, which could have serious implications when attempting to utilize the terminal for highlighting specific areas in the refresh mode of operation. The concept of highlighting as applied within SPD is to provide a method of directing the user's attention to a particular segment of the frequency spectrum of current interest. The method used is to provide the areas of interest, as specified by the user, as a display of greater intensity than the frequency segments surrounding it. This concept is identical to that utilized by the original SPOTLIGHT system.

If, in fact, any degradition exists for whatever reason, is it significant enough to discard the concept of a storage display, or rather is it just enough to justify the expenditure of additional funds for further hardware development. Or, for the best possible condition, is the degradition either non-existent or at least insignificant enough to not affect the system's overall performance. These are the questions which must be answered if the implementation of a DVST is to be seriously considered for SPOTLIGHT.

III. SPOTLIGHT AS IMPLEMENTED ON THE PDP-11/50, TEKTRONIX 4014-1 SYSTEM

A. SYSTEM HARDWARE

As mentioned in the INTRODUCTION, the processor utilized for the evaluation described within this paper was the Digital Equipment Corporation PDP-11/50. The system as finally implemented includes a direct access memory of 124K words along with three Control Data disk storage modules of the 9762 series, two digital RK-05 disk units, a seven track magnetic tape unit for data input and the TEKTRONIX 4014-1 display terminal for the sole user interface. Currently data is transmitted to the display terminal via a serial interface being clocked from the terminal itself at a rate of 154K baud. However, a new and faster interface is to be installed which will operate in the parallel mode and will, in addition to providing for a faster data transfer rate, continue to permit asynchronous operation for the user to CPU and CPU to user communication. This interface is functionally equivalent to the NTDS interface of the Navy's AN-UYK-20 mini-computer. The addition of this asynchronous capability should aid in utilizing the terminal to its fullest interactive capabilities.

Also awaiting implementation is a VERSATEK raster scan hard copy unit which will add the dimension of an optional permanent record of a display as seen by the observer. This feature comprises a new addition to the signal processing system as implemented at NPS. It is a desireable feature which would aid in later analysis of key points as well as for historic purposes.

Concerning the hardware implemented, it is of interest to realize that of the three CDC-9762 disk units available, only one segment of one unit was utilized. However, even with only the single segment there was sufficient space (32 mega-bytes) to store the total contents of one average data tape. This storage capability enables rapid access and display of previously displayed data as requested by the observer. Additionally the capability exists for an operator to place data on disk storage and thereby forego the use of tape in later processing. This feature of bypassing the tape would result in more rapid processing and display than when utilizing the tape system.

The evaluation as completed was on MUNIX [1], which is an NPS originated version of the original Bell Labs UNIX [11] operating system. Due to the nature of a time sharing system, this evaluaton does not present the optimum conditions for overall system response times. This situation does not lend itself to an overly optimistic interpretation of results as compared to a devoted single

user situation, thus yielding a conservative estimate of system capabilities. The programming language utilized for this evaluation was the C language of Bell labs [4,10] which is a higher level language with many features for system level development. This in itself represents a change for the better as compared to the XDS-9300/AGT-10 system, the original implementation of SPOTLIGHT was on the XDS-9300/AGT-10 system, which required a substantial portion of the programs to be in a lower level form of assembly language.

An area for clarification at this point is with regards to the actual hardware implemented. The equipment listed at the beginning of this section was the actual physical plant available on the NPS PDP 11/50 installation. It does not represent the minimum equipment level required to support the SPOTLIGHT system for a DVST. A minimum equipment availability would be a mini computer with 36K to 48K of user available memory, a magnetic tape unit for raw data inputs, a DVST display terminal and if possible a small disk unit. If the disk unit were unavailable the only significant difficulty would be that any user request requiring access to previous data must rewind the magnetic tape. This would be a slower process than the use of a disk, but as for the actual display the same general capabilities would exist.

B. ACCOMPLISHMENTS

1. User Level Considerations

Prior to effectively discussing the results of the evaluation it is necessary to present the basic concepts of the program design to establish a common reference point. Although this was to be primarily an equipment feasibility evaluation, it must first satisfy the requirements of being a dedicated, user oriented interactive system. To satisfy these requirements (which are general at best) the system must provide rapid, definitive response to user requests while requiring a minimum of program requested interaction. It must also provide extensive processing and display capabilities to the user if the necessary levels of flexibility for meaningful implementation in a signal processing environment are to be realized. However, this need for flexibility should not be permitted to override the design feature of simplicity of operation.

The display must also be such that the operator is not overwhelmed by a complex display format or by a complex instruction structure. The needs for both rapid response times and the combination of computing power with display power were mentioned by Sutherland [14] as prime concerns for the design of any computer graphics application. Primarily these needs referenced the requirement to give the operator the flexibility he requires to accomplish the task in an easier manner than would be possible without

the computer's assistance. If, in fact the task is more complex or difficult to accomplish with the computer's assistance, the problem is resolved, the operator will not be likely to use it. Therein lies the difficulty, the user portion of the programming effort must appear simple and convenient to implement, but it must also be a capable and efficient computing tool.

While simplicity is an important consideration it should not be permitted to cause the display or command structure to be so limited as to degrade its usefulness or flexibility. This requirement is of particular importance since the program's capabilities in presenting the data to the analyst in the most desirable format possible are of prime importance. Without these goals there would be no need for the existance of either SPOTLIGHT or SPD [8].

In order to allow the operator to utilize his signal processing efforts most efficiently it is desirable to keep the level of required user interactions to a minimum. This programming restriction is necessary so as not to detract the operator's concentration from the task at hand. The SPD program design permits this by allowing the user to either manually control the appearance of a new data page, or to allow automatic system control on a continuous timed basis. This automatic control is the primary method implemented to minimize user interactions. Therefore, while under system control, the only interactions required of the user are to initially command

execution to begin and to react to system level computing faults. The optional interactons are to reset display or processing parameters as required by changing data characteristics, to review past data or to terminate processing.

The user commands provided for SPD were designed to be simple for use and understandable. To accomplish this, all commands key on one letter followed by the appropriate input value, but do not restrict the user to this level if typing more than one key letter is more acceptable to him. This facility was implemented as a method to allow each user to tailor his own command structure to as great an extent as possible. A capability intended to assist users in adapting to the control functions as currently implemented. For further description of the command formats and meanings the reader is referred to the SPD User's Manual [4] which is comprised of a copy of the User's Manual for the SPD system of programs and a program listing of the initial implementation.

The concept of help files as a means of assisting new users with various levels of information is, as always in an interactive environment, a desirable feature. These files should be organized as several distinct units with each providing its own level of knowledge such as initialization of the system, the command control structure; the actual commands; and finally some hints as to desirable parameters for specific types of data. As of the time of completion of this thesis these files have not been

implemented and are mentioned only as a feature which should be installed in the future, provided the concept is to be further developed.

With the inclusion of user oriented help files the preliminary user interface segment of SPD, as necessary for system evaluation, will be complete. However, before a total system is completed there is sufficient area for improvement and further evaluation.

2. System Level Considerations

The SPD concept requires that the actual program execution be as rapid as posssible, particularly in such time consuming areas as hidden line elimination. This desire for execution speed resulted from an attempt to provide for system display at a rate much faster than real time, thus enabling more rapid data analysis if needed. The main points of interest here center around the following, typically time consuming areas:

1. hidden line elimination;
2. maintaining required calculations to a minimum;
3. preventing the initiation of a display until all necessary data processing has been completed;
4. compression of data required for for transmission to the terminal;
5. preservation of the original data in its original form to provide a means of rapid recall if desired; and
6. a minimum of time to monitor the keyboard for user commands.

Hidden line elimination is an area where the programmer can utilize very elaborate and precise algorithms to provide not only line elimination, but also shading to emphasize the third dimension feature. Or, alternatively, he may choose a very simple algorithm providing for only line elimination. The difficulty with the complex algorithms is that while they do provide for impressive displays, they can require an excessive amount of either computing time or memory [7], which are resources not contained in abundance in the anticipated SPD environment. Fortunately, the hidden line elimination for this application does not require the extended features necessary for the detailed three dimensional graphics. This is due primarily to the characteristics of the display format as implemented in SPD. That is, each data line consists of only two dimensions, the third is utilized only to facilitate display of multiple data lines on the same page, providing the analyst with a better perspective view of his data. Therefore, there is no need to consider the problems associated with the more complex three dimensional geometric solutions.

Thus, the hidden line elimination problem reduces to one of simply evaluating each new line segment to determine if, at any x-coordinate the new y-coordinate goes below the previous maximum level for that position. If so, evaluate the line to determine which portions of the line segment should be removed and which should remain.

This evaluation could be accomplished through any one of several methods using concepts which actually calculate the equation of the line, before deriving the points of intersection and drawing a line to that point. Or, as an alternative he may choose to check iteratively each point in the line one at a time. For the SPD application the later approach was implemented with the exception that not every point is evaluated. Rather, an even spacing of points are evaluated whenever the removal routine is called. This compromise was an attempt to minimize algorithm errors due to a changing horizontal scale factor while also minimizing required computational efforts. Additionally, since the hidden line elimination routine is not utilized until a particular line segment is found to have need of it, the efficiencies are even greater for this application, both in terms of speed and accuracy. For an example of the accuracy of this method of hidden line elimination reference figure 4 which uses a rotation factor of +60 degrees, as measured from the vertical plane, and a horizontal scale factor of 2.

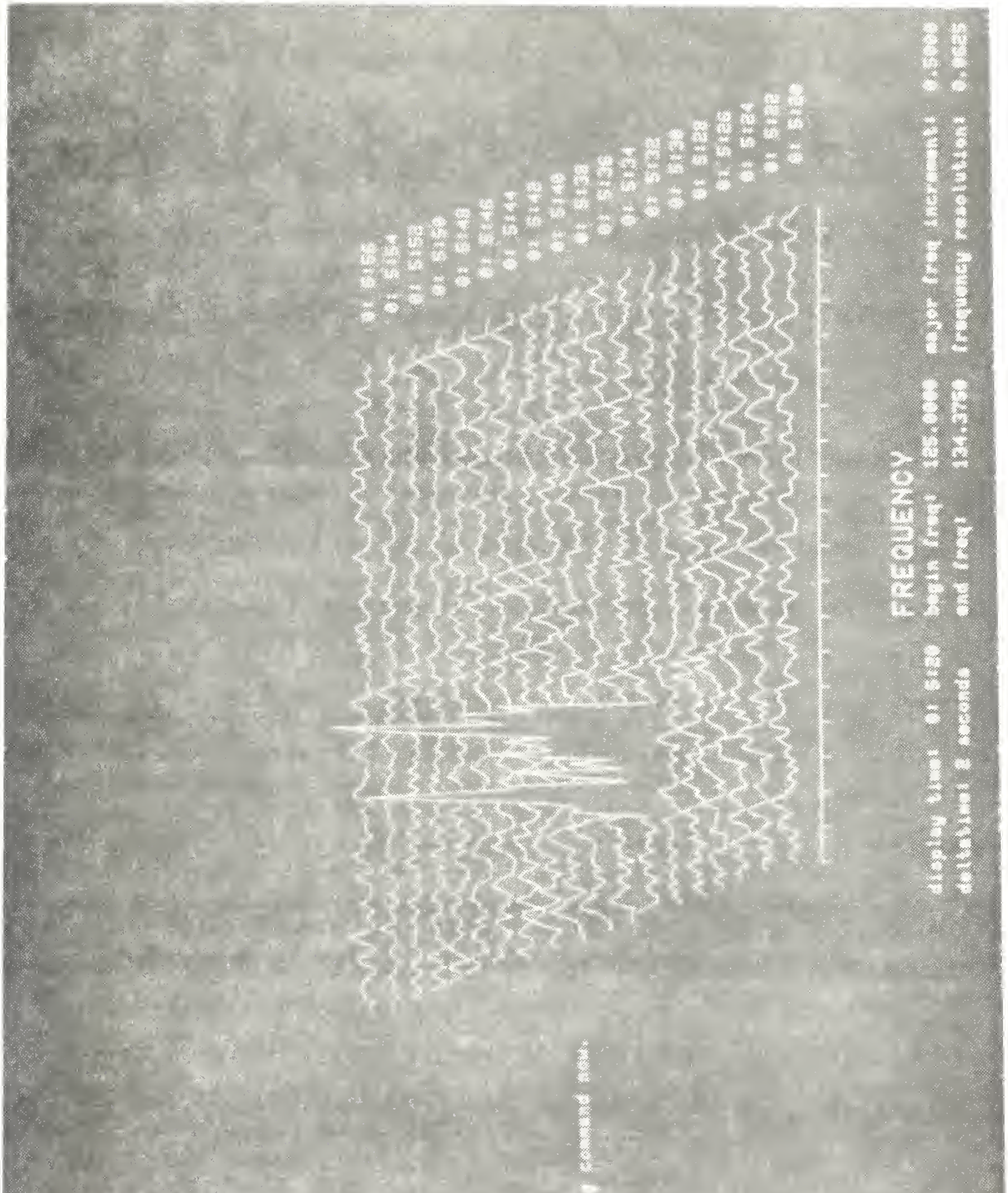


figure 8: Simple hidden line elimination accuracy

Since time is such an important factor, the hidden line elimination algorithm has been reduced to the point where a minimum number of data evaluations are required. The concept is that only one evaluation for each end point of a line segment is required to determine the need for further processing. If this need exists the further evaluation is accomplished by referencing a two-dimensional array which contains the current maximum y-coordinate for each program addressable x-coordinate. As a result, the only elimination calculations required are to address specific elements within the reference array and then to divide the new line segments into equal but smaller segments, reference figure 5. At this point an iterative comparison is performed to determine the exact point of intersection within the accuracy permitted by the addressing. Therefore, it is a simple, effective and very rapid line elimination process which is not affected by the number of display lines drawn. Processing time is adversely affected as the number of segments within a line increases. This effect is due to the increased number of line elimination evaluations which must be made for each display line. Accuracy is affected by the use of excessively large horizontal scaling, although for those scales which are reasonable, the accuracy is more than sufficient. Reasonable within this context implies a width factor which, for the current number of lines requested per page, will permit the display of the entire data

field. For example, if a large scale factor were combined with a high degree of rotation then it is possible that the last few lines displayed may be truncated due to exceeding the addressing limits of the screen.

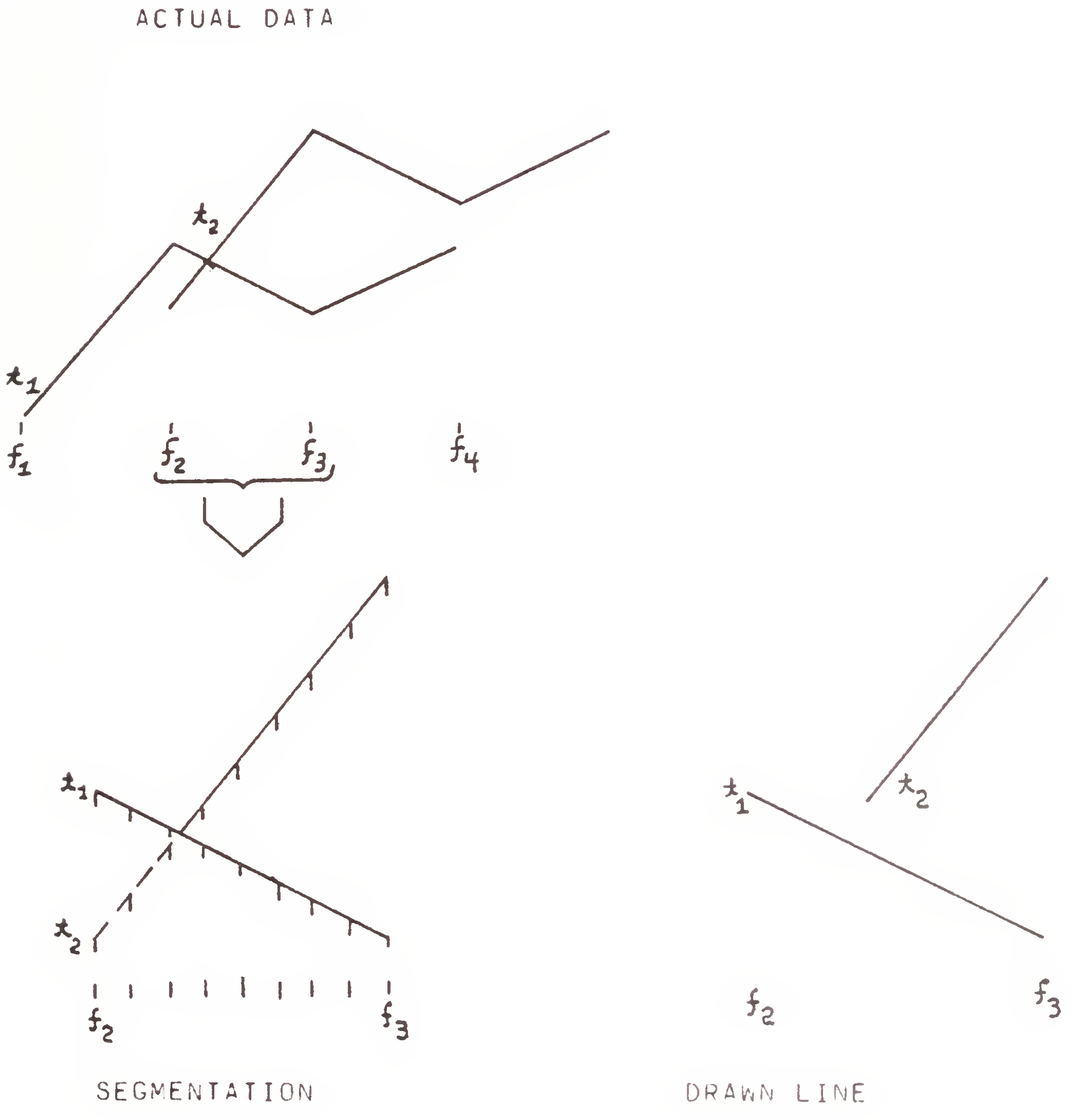


figure 5: Line segmenting required for line elimination

Extended calculations which are required of the program have been minimized in order to maintain the stress for execution speed. Indicative of this is that the only areas requiring extensive calculations are those necessary to apply the user revised rotation parameters to the input data on a one time only basis. All other efforts are devoted to the actual data input and output necessary to provide for both historic storage purposes as well as display. The major problem here is obtaining the fastest possible data transfer rates from the CPU to the terminal for display. This area of maximum data rates presents some difficulty primarily for the pictorial display during the refresh mode of operations although it is a convenience factor for other modes as well.

In the interest of further resolving the data transmission requirements the program does not allow the initiation of any draw or move command until such time as all processing for the current display update has been completed. At this point all necessary information is contained within a single buffer awaiting the initiation of a uninterupted output. This continuous output terminates only with the end of file or an error indication as appropriate. Consequently, the only limitations in data transfer experienced are in the areas of:

1. maximum data transfer rate at the CPU interface;

2. level of system overhead required to effect the actual transfer; and

3. maximum rate at which the terminal can accept data.

In the application to SPD, factors 1 and 2 above have been manipulated to a substantial degree in order to progress from the previous maximum data transfer rate of 9600 baud to the current level of 154K baud. Within the near future factors 1 and 3 should be modified to provide an even faster rate through the use of a parallel interface. Based on the observed performance the 4014-1 terminal, a data transmission rate of 154K baud represents the minimally acceptable rate for the refresh mode of operation as implemented in the SPD environment. This is not to imply however, that a more rapid transfer is not desireable nor worthy of additional hardware experditures, since for SPD the greater the refresh capability the more effective its performance will be.

Another field requiring some effort was provision for a reduction in the amount of data flow (data compression) required to present a given point and thus, a line segment. Without this data compression each point transmitted to the terminal requires five bytes (in the 4096 x 4096 addressing mode, or 4 bytes in the 1024 x 1024 mode) to define its screen address. Therefore, a line segment will require, without reduction of any type, 10 bytes of

data to define it or 8 bytes if the 1024 addressing option is in effect. However, by utilizing the storage registers of the terminal, graph mode memory in TEKTRONIX terminology, the actual data flow required may be as small as 1 byte or as large as 10 bytes. Thus, the possibility for up to a 90% reduction in data flow for a given line segment is possible. This data optimization is directly affected by input data characteristics and is aided by the existance of small changes in the signal amplitudes between frequencies and the resulting screen addresses. The result is that input data whose amplitude is rapidly changing or erratic will decrease the effects of data optimization, whereas stable signal amplitudes will provide the greatest gains in optimization. Therefore, the effects of the data optimization are very data dependent and as such not reliably predictable.

A final area for concern was the time required to programmatically monitor the user's keyboard for commands at the level required to provide a responsive system. The options here are to continously monitor the keyboard, to monitor in given time increments or to devote no direct processing time to the task at all. The use of the last alternative is one which allows the system to accomplish the keyboard monitoring and interrupt the main process if, and only if an appropriate user interrupt occurs. For the SPD implementation the later approach was adapted for two reasons. First, to be an efficient interactive system the

program needs to continually monitor the keyboard for the user's commands. Secondly, if a method were devised to provide continual keyboard monitoring substantial overhead would be incurred if adequate response were to be provided. This continual monitoring is relatively easy to accomplish within the constructs of the C language itself, however no other processing in enabled until the user provides an input. It was due to this lock-out of other processing that attempts to actively monitor the user's keyboard within the SPD routines was an unacceptable solution and was discarded. Consequently, the last alternative proposed was the one implemented.

The alternative implemented was to enable a system call to intercept a specific interrupt (in this case the RUBOUT command) and at that time take the appropriate action. Thus, no time is consumed to monitor the keyboard during the display processing, but the response to the user desires is essentially immediate. This implementation provided the best solution to the user response problem by incurring no additional software overhead for keyboard monitoring.

With the data flow optimization efforts complete, the system level software and hardware overhead minimized the next major area of concern was addressed. This area was the preservation of input data in its original form for later return during analysis. However, this was of concern only because SPD utilizes a disk storage module to

provide maximum data access times. If a disk module is not available, it is not necessary for effective SPD performance, then this area would not be one of concern to the system designer.

The method utilized by the SPD routines to preserve the original data is to initially read the data from tape and immediately place it on disk storage. Once this has been successfully completed, control is passed to another program segment and the data of current interest is read into a data buffer for manipulation and display. Note here that all data manipulation is accomplished within this buffer and at no time is the data in the buffer returned to replace that already on disk. This procedure enables the user to return to previous data entries at anytime during the analysis, and have the original data available. This capability of recovering previously displayed data without the requirement to resort to the use of tape, which would create an unreasonably slow response time, was a very desirable property for analysis convenience, and is not a necessity.

In addition to establishing the system as a fast means of accessing and displaying data, the programs need to be easily maintainable. This is of prime importance if the routines are to be used in the future with any capability for improvements to be implemented and evaluated. Improvements not only in the sense of methodology of creating the display but also for new concepts for the

processing of raw data once the equipment for on line Fourier transforms is installed for evaluation. This equipment, a CSP-30 signal processing controller with associated memory and a CSP-4001 array processor will provide the capability for concurrent Fourier processing and display of raw data. A capability not available on the original SPOTLIGHT installation.

The concept of SPD requires that it exist in a developmental rather than a strictly operational one. Consequently, SPD must be easily maintained in its current form, yet allow the capability for simple expansion and modification in the future.

C. PROGRAM CAPABILITIES

As the programs utilizing the PDP-11/50-TEKTRONIX/4014-1 version of SPD must exist in a totally interactive implementation, there are certain minimum programming requirements which must be met. These requirements are not unique to this system or type of application, but they must not be deleted from consideration because of their commonality. There should be no limitations in the availability of program execution capabilities to the operator at anytime during the analysis process. That is, at any point during the program execution the user should be able to exercise any control option of which the program is capable, without the need to halt and restart the entire process. This capability involves such

features as being able to regress in time at the will of the user and recall immediately one or more data entries in their original form. The original display parameters such as amplitude scaling, rotation, horizontal scaling or frequency scan, while they actually modified the data prior to display, should not have modified the data stored on the disk system. This, in fact is the case, and as such enables immediate recall of any previous data entry which is stored on disk in original form (for the Control Data units this should cover all data entries received from relative program time 00:00:00). This capability cannot, however, be extended to cover requests which require the resampling of the original raw data prior to the actual calculation of the Fourier Transform. These requests (e.g. varying sampling rates, different sample overlaps) will necessarily cause execution delays due to the need for the system to back up the data tape and re-examine the raw data utilizing the new processing control parameters.

The above discussion illustrates an interactive capability which is a necessary feature in this type of implementation. All control parameters both for display and processing are dynamically controlled by the user at any instant throughout program execution. It is through this system of control modifications provided to the user, that the flexibility in processing and display necessary for an effective analysis tool is derived.

All control parameters utilized by either the processing routines which use the CSP processor, or the display routines are dynamically controlled by the operator. These parameters are varied through the same command sequence in every case, thus creating no special instruction sequences which the user must remember, thereby decreasing the possibilities for user command error. These methods of implementing the command structure were designed to aid the analyst in easily and quickly molding the system parameters to meet his immediate display goals. The degree to which this goal was realized remains to be completely evaluated.

The description of the method for interactively controlling the processing parameters completes the discussion of the basic concepts underlying the design of the SPD routines. However, there remains one area of particular importance for this application when considering the direct view storage tube format, namely its highlighting capabilities during execution. While this may not have been much of a problem with more specialized AGT-10 system it is a significant one with the direct view storage tube (DVST) format of particular interest since the DVST was not designed for use in a large scale refresh mode.

The TEKTRONIX terminal has a requirement to be refreshed at least 30 times a second in order to provide a flicker free display in any refresh mode (i.e. character or vector). However, for character generation the maximum

capability of the terminal's character generator is 4000 characters a second in the refresh mode. This is to be compared to a maximum capability of 1000 characters a second in the storage mode. Due to the relatively slow character generation rates and the data flow required to switch from alpha-numeric to vector mode, no refresh of alpha-numeric characters has been attempted during the SPD development and all text is written in the storage mode.

Considering the vector drawing capabilities of the terminal, the conditions are substantially better. Two characteristics are critical here in their affect on the actual terminal capabilities. These factors are first, the maximum baud rate which the interface is capable of transmitting data and the maximum rate at which the terminal can accept it. The second factor is that the terminal has a maximum vector drawing rate of 5000 vector inches per second. This includes distance between consequtive points, even if a vector is not drawn, i.e. a move command. Note also that the maximum baud rate can be a factor in the character generation if the rate is less than 40K [15], however the baud rate in this implementation was 154K baud and as such was not considered to be a factor. Similarly, the 5000 vector inch per second limitation was evaluated and found not to be a limiting factor in this analysis, rather it was the maximum data transfer rate which restricted the level of performance. For the maximum number of data lines permitted per data page and the

maximum permitted width of a given spotlight, the vector inch feature will average on the order of 1500-1550 vector inches a second. These figures allow for an average line segment length of 1/4 inch, a total of ten line segments for each data line spotlighted, twenty data lines being refreshed and 30 refresh cycles a second.

The original implementation of SPD utilized a serial interface between the processor and the TEKTRONIX display. This interface allowed maximum baud rates of 9600 baud when using the system clock, or up to 38K baud when externally clocked from the TEKTRONIX. The next stage in the development was to implement the an interface which allowed effective baud rates of up to 154K baud which, based on the initial analysis, was the minimum acceptable rate for the highlighting application. As was the case with the faster rates on the second interface, the TEKTRONIX terminal clock was used to meet data transfer requirements. The TEKTRONIX clock is capable of increasing the rate of 154K baud to a effective rate of 304K baud. A rate which, if available would obviously be much preferable to the one currently in use for the highlighting application.

It must be recognized at this point that the SPD application requires that a large number of short vectors be drawn. This requirement creates a need for defining many line segments and a corresponding need for large data-flow rates to define them rapidly enough to yield a flicker-

free highlight. This characteristic will then tend to emphasize the data transmission limitations while minimizing the effects of drawing speed limitations. As a result, in a different application the user might easily find the maximum length of drawing available to be more a limiting factor than the actual data transmission rate. This establishes the actual programming considerations for the initial system design and implementation along with a basic description of the efforts required for a minimal highlighting capability. These standards were basic and apply to most interactive systems, but still warranted an introduction at this point in order to once again establish a common reference point in this area of concern for later discussions.

IV. THE DISPLAY DESIGN

A. THE PHYSICAL FORMAT

As mentioned previously, the display to be provided by SPD for user analysis was to be as nearly a duplicate of the original version of SPOTLIGHT as possible. In particular the display was to be of waterfall format with the third dimension representing the time axis. This time axis was to be implemented in such a manner as to place the most recently processed data line at the front of the screen, reference figure 6. The frequency spectrum under analysis was to be represented on the horizontal axis and the signal amplitude on the vertical. Other features to be continued as before were the highlighting capabilities, a single line display above the main one, image rotation and scaling. All features which the users evaluating the system originally found to substantially enhance their analysis capabilities.

With the SPD version the maximum number of lines for a given page is a variable parameter with the number of lines displayed permitted a range of from one line to a maximum of twenty. This number represents a deviation from SPOTLIGHT in that it permitted a maximum of ten lines displayed at any one time. This value, for both SPOTLIGHT and SPD is one which the user can reset at any time during the analysis process. However, with respect to the data

page display design, the decision was made to deviate from the SPOTLIGHT format and display the most recent line behind the one previous to it in the time domain. This decision will be justified in later sections but is primarily due to the hidden line problems which would result from the other approach while in the DVST environment.

Other deviations worthy of note here are that with SPD, the harmonic group highlighting could not be used without limiting the number of display lines in each group. This group highlighting restriction is due once again to the problems relating to high data flow rates necessary to highlight and those which are currently available. If a single line option is in effect then the highlighted area does not include a highlight of the single line option, instead a curser is placed below the initial point on the single line image. Once again this is a restriction when compared to SPOTLIGHT where the highlight effect was carried through to the single line image. These limitations are directly caused by the problems associated with the data transmission speeds and the amounts of data which must be passed to enable a refresh type of operation. If more speed is obtained in the area of data transmission then some, if not all of the deficiencies, relative to SPOTLIGHT, can be eliminated.


FREQUENCY

Along with the actual display of data lines each page has displayed as text the initial frequency of the display, the display time for the first line of the current data page, the time delay between data lines, the last frequency shown on the current page, the frequency span between major indices on the graph base line, and the basic resolution of the data. All of these parameters are based on the current processing parameters at the time of the initial display of the page. If any of these parameters are changed during execution, the current page will be erased and re-displayed to reflect the new parameters. The photograph in figure 7 illustrates the text provided for user analysis.

As a means of supplementing the basic description appearing below the horizontal axis there also appears, beginning at the upper left corner of the screen, a frequency readout for the beginning of the most recent highlight selected. This provides the analyst with an exact display, to a tolerance within the basic resolution of the data, of the beginning frequency of the highlight, and is continually updated as the highlight position is changed. Since this, as does all text display, utilizes the storage mode, all frequencies the user has specified at any point during the current page will remain displayed, in their original order of occurance, with the most recent request appearing at the bottom of the list.

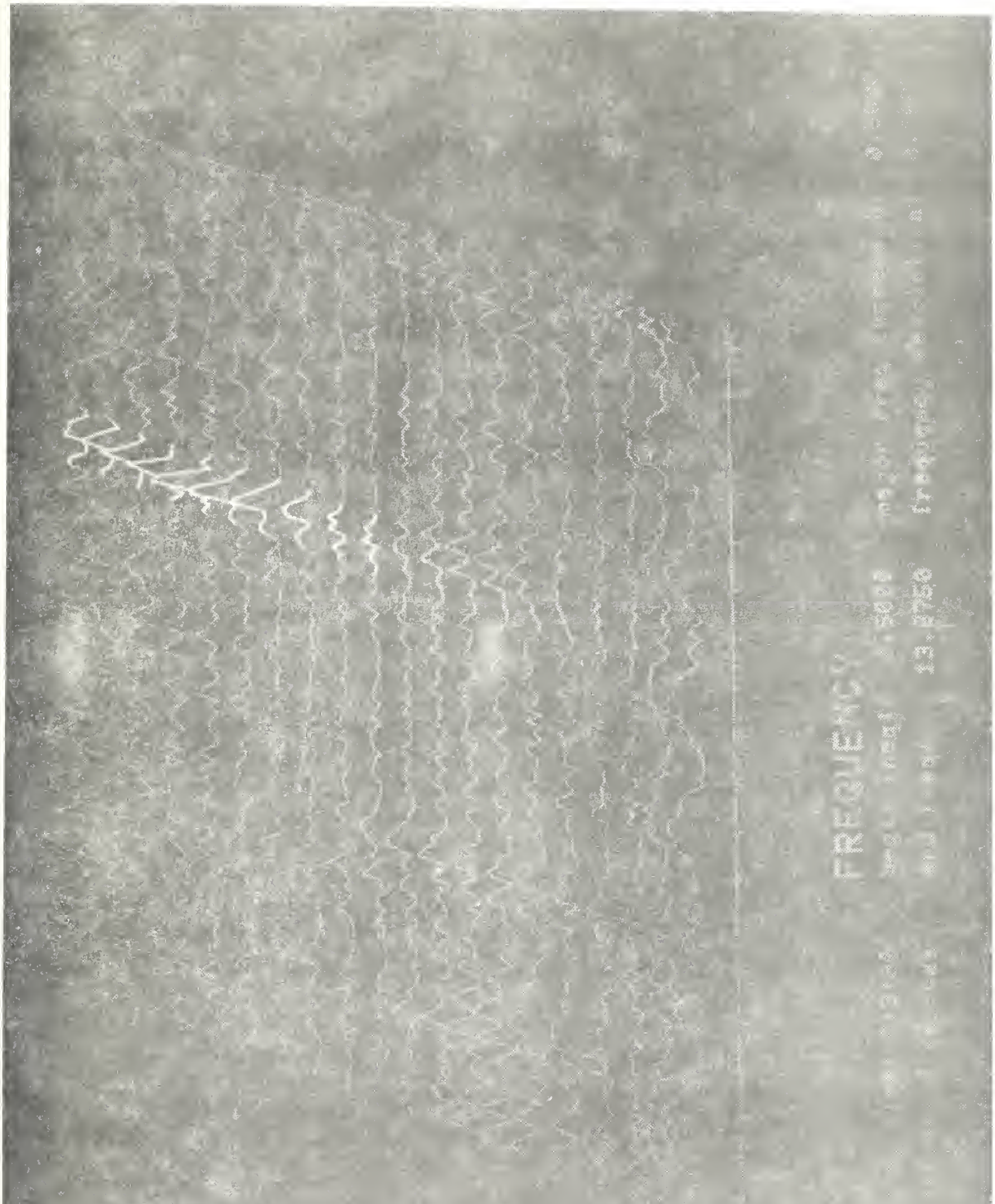


Figure 2: Textural data for [illegible]

In addition to the highlight capabilities the user also has the option of any single line displaying at the top center of the screen (figure 8). This single line appears as an individual display utilizing all display parameters as specified but without hidden line elimination corrections which may have occurred initially.

For the DVST display version of SPD this capability is of particular importance since the most recent line appears behind those preceeding it in the time domain. Thus, small changes in the signal amplitudes may be missed due to the hidden line elimination process. The significance of this problem grows as amplitude and rotation factors increase. However, while this poses the possibility of serious difficulty it has not been observed to pose a substantial problem with the test data evaluated to date. It is due to these problems with the hidden line elimination and the possibility of lost data, that the default option for the single line is the most recent line displayed. Additionally, if the user selects a single line display and then issues a highlight request, a curser will be used to indicate the initial freqency of the highlight on the single line image. The highlight, as mentioned earlier, does not illuminate the actual line segment since the amount of data transmitted during the refresh is so critcal to the preservation of a flicker free display.

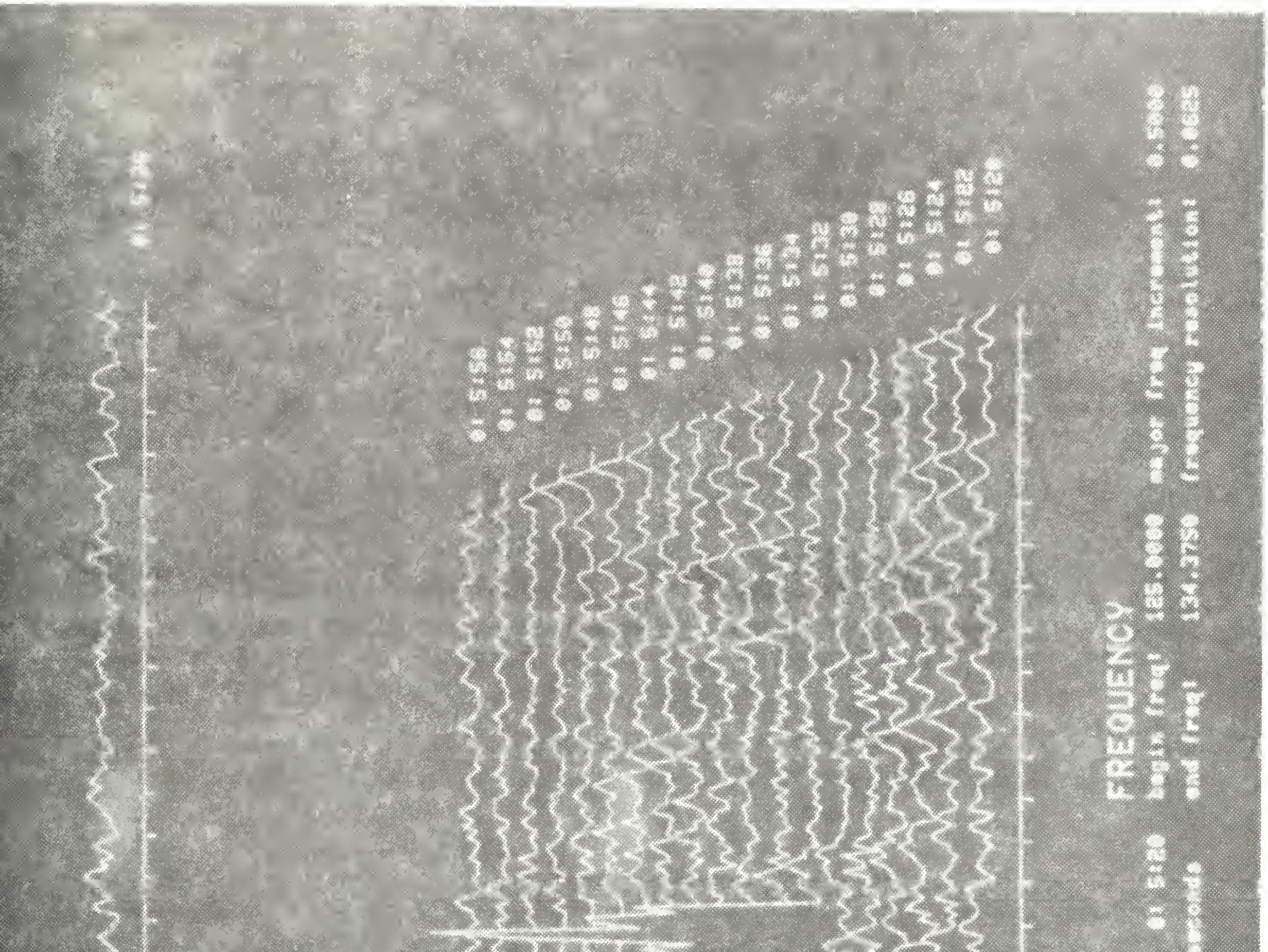


figure 8: Single line option invoked

The final text which is routinely displayed is the system echo of user commands. Since this is a DVST display, echoed data returns from the processor as a default condition, in the storage mode. Utilization of "write-thru" was not employed since it requires the transmission of additional data to initialize and then to reset storage mode upon completion. As a result all transactions conducted on the terminal will be recorded on the screen until such time as a new page is created. This property of the DVST can be seen as either an advantage or a disadvantage depending on the number and length of the commands issued by the user. As an advantage it provides the user with a command chronology for later reference while the current page is displayed. As a disadvantage there is the problem that if a substantial number of commands have been issued for the current data page, then the display may have a cluttered appearance, thus detracting from the effectiveness of the display for analysis purposes. As an aid in decreasing the severity of this affect all system prompts to the user have been minimized both to save space on the screen, and in memory. Meanwhile simplifying the user's efforts to interpret the data as displayed.

B. POSSIBILITIES FOR USER MODIFICATION OF THE DISPLAY

Above all, the SPD display system controls need to be flexible enough that each user can modify its physical appearance easily and quickly to optimize his recognition capabilities. This point has been continually emphasized in order to establish its importance in the overall system design, and is an area whose importance cannot be overestimated. To provide this necessary flexibility a number of control parameters have been included which allow the operator immediate control to modify the physical appearances of the display. These controls are as follows:

1. display rotation;
2. amplitude scaling;
3. frequency scaling (horizontal axis); and
4. vertical spacing between display lines.

This area represents another deviation from the SPOTLIGHT implementation, once again due to hardware limitations. The deviation is that if a change is desired, the appropriate parameters must be individually typed by the user in a distinct form, while operating from the command mode. A limitation not always observed in the SPOTLIGHT version due to the Adage system's utilization of dials and function buttons as an optional input medium to provide continous control of scaling and rotation functions. The SPOTLIGHT method seemed preferable but could not be implemented on the TEKTRONIX except through

additional equipment which would add to both the expense and complexity of the system. Thus, the operator can only specify discrete increments in any of the variable control factors and must do so by entering into the command mode level of operation.

The user control of display rotation is a valuable option particularly for the DVST system since it enables him to change the perspective of the display at any time. Thereby changing the line segments which have been affected by the hidden line elimination algorithm, as well as providing the attainment of a more effective viewing angle. Similarly, if a new trend in signals is observed it is possible that by changing the viewing angle the user will be better able to detect it as a new trend. The range of values available to the user and their actual implementation is described in the SPD System User's Manual [4]. As for the actual differences in appearances realized from changing the display parameters for rotation the reader is referenced to figures 9 and 10 which represent a viewing angle of 60 degrees (the default condition) as well as an angle of -60 degrees.

Of even greater importance to the user is the capability to directly and immediately affect the amplitudes of the data as displayed. In this area the capabilities required are the ability to both amplify and to reduce the data's initial amplitude. This enables the user to allow for very weak signals, or for very strong ones through

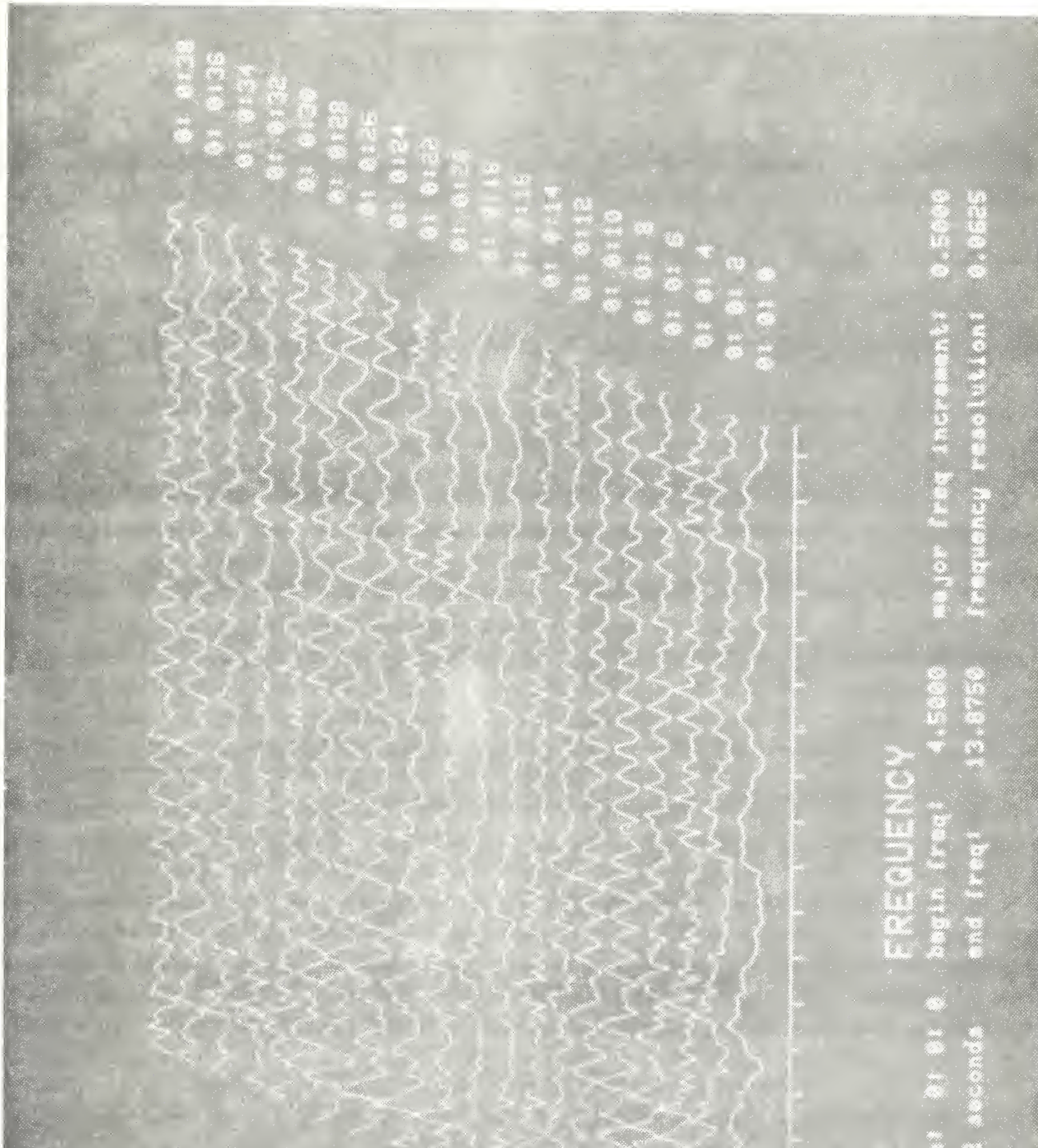
actual modifications to the amplitude of the display. For SPD this control is provided through allowing the user to specify a factor which results in amplitude changes effect in increments of powers of 2.

In addition to the capability for directly affecting the displayed signal amplitudes the user may control the horizontal spacing between displayed data points. This horizontal scaling is accomplished through utilizing multiples of the basic spacing, which for the current default parameters, is eight address points (approximately 0.028 inches). This feature may be utilized to expand or contract the display to whatever degree necessary to optimize the analyst's efforts and is limited only by the screen width. Reference the SPD User's Manual, [4], for a further discussion of the horizontal scaling. In addition to the horizontal spacing controls the user also has a vertical spacing control at his convenience. This feature is perhaps more useful than the horizontal since it is used to increase or decrease the vertical distance between consecutive display lines. This variable vertical spacing capability can be of significance since, as the user increases the rotation factor the absolute vertical spacing decreases, thus increasing the need for hidden line elimination. Along with this increase in the need for hidden line analysis is a corresponding increase in the possibility of lost display data due to line elimination. Consequently, if the operator finds the greater rotation angle

more convenient to use and needs to decrease the hidden line elimination problems, then he can easily increase the vertical spacing between consecutive display lines while maintaining the desired viewing angle. This rotation capability is a useful tool for maximizing the analyst's recognition capabilities and overall effectiveness. A more detailed discussion of this implementation is found in the SPD User's Manual.

Actual changing of the display, or processing control parameters can be accomplished as many or as few at a time as the user desires, and always from the same execution level within the program. Once the user has initiated the command mode he has immediately available all of the system control parameters which can then be modified at will. Again, a simple capability to implement, but one which is very useful in terms of user convenience.

This completes the concepts and features of the actual display design. The primary goal was to discover and implement the optimum methods for a DVST format in terms of user convenience and effectiveness. The degree to which this was successful awaits the actual end user evaluation stage, however tests to date have been encouraging.


FREQUENCY
display time: 01 01 0
begin freq: 4.5000
major freq increment: 0.5000
deltatime: 2 seconds
end freq: 13.8750
frequency resolution: 0.0625

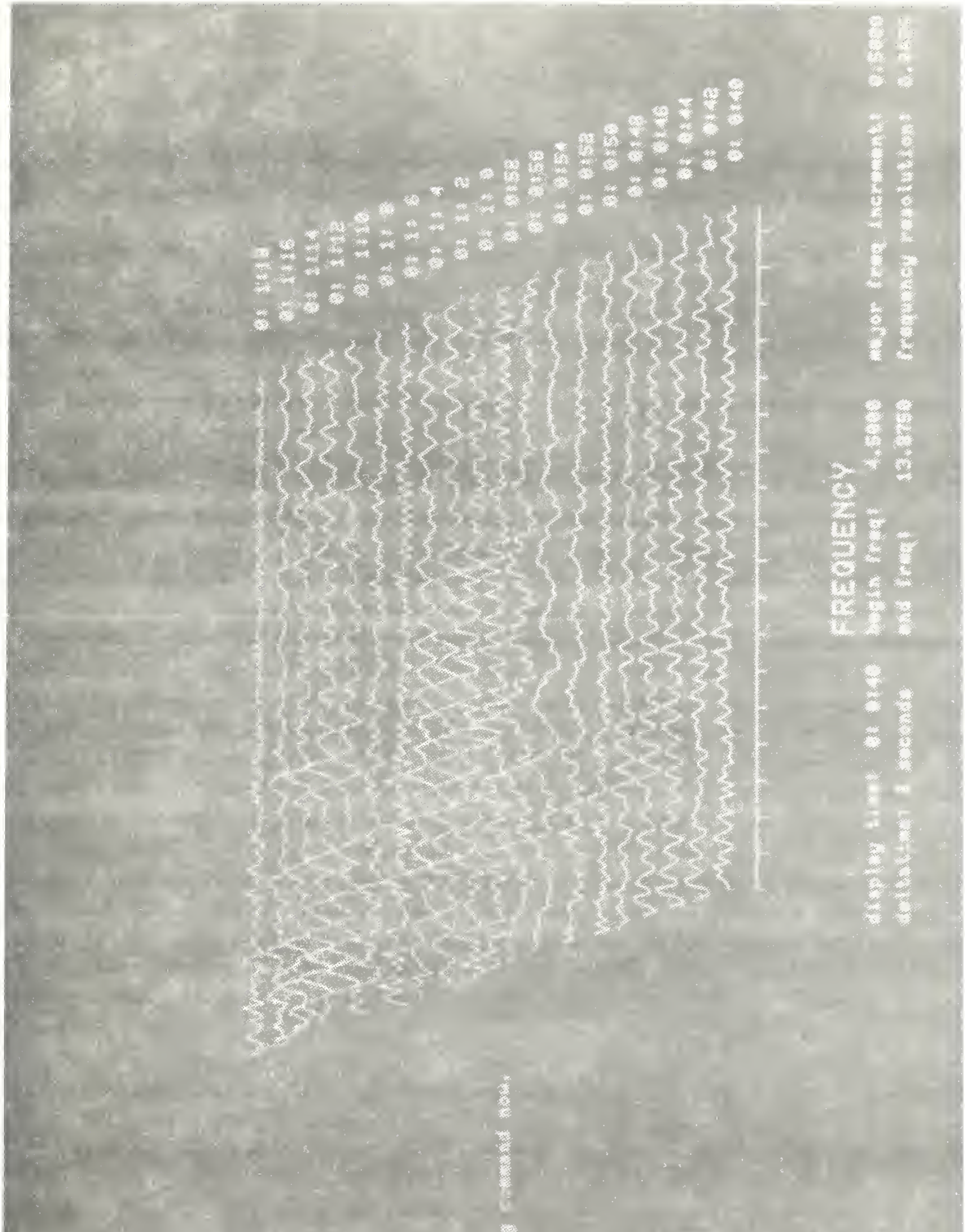


Figure 1[illegible]: Rotation factor of -90 degrees

C. PROBLEMS RESULTING FROM THE USE OF A DVST

As with any compromise solution there are always disadvantages as well as advantages, the DVST as applied in the signal processing environment is no exception. The DVST attempts to alleviate the processor, or itself in a stand alone configuration, from the need of conducting continuous display refresh. Associated with this advantage however, is a distinct disadvantage. After the image has been stored for a long period of time the background will begin to glow as a result of the low speed flood electrons gradually disapating the negative charge of the storage grid. The increase in background intensity gradually decreases the contrast between itself and the stored image (fogging). Beyond a certain point this fogging effect is of sufficient intensity to render the stored image indistinguishable from the background, thus making the stored image useless.

The problem of fogging is one of the major detracting points to the use of the DVST for general computer graphics. This is particularly true of applications requiring the presentation of an image for relatively long periods of time. The typical DVST can display a stored image for periods of up to one hour [7], before it fades to a completely unuseable level. The 4014-1 terminal provides performance somewhat greater than this one hour in the evaluations which were conducted. However, for the SPD environment displays are maintained for such short

periods, usually not more than two minutes, that fogging was determined to be an insignificant factor. This low display maintenance time is due primarily to the continual data flow which will normally stop only for display manipulation as requested by the user. However, manipulation will typically result in the erasure and re-display of the current data page, thereby eliminating the fogging problem.

A disadvantage which is judged to be a factor in the SPD environment, however is the lack of a selective erasure capability. It is primarily due to this problem that the decision was made to place the most recent line behind those already displayed on the screen. This is not the preferred solution for the display as it would be more appropriate to place the newest line at the front of the display. Thus allowing the analyst to preview each new line, without the possibility of hidden line elimination removing any data, no matter how insignificant. However, the preferred solution would have necessitated the total erasure and re-display of the screen for every new line of data. This solution called for the display of the current line, allowing the analyst to observe it for the period of time corresponding to the time needed to process the new data and then erasing the display and displaying the new data. Since new data is made available at the rate of one line every two seconds under the default conditions, that would require one page erase every two seconds just to

keep up with the processing capabilities of the system. The speed at which lines become available for display presents an even greater argument in favor of placing the most current line at the back of the display. When the user goes into a replay mode of display, e.g. a move back in time, tape access is not necessary for SPD. Consequently, the only delay which exists is the time required for actual display processing. As previously mentioned this time has been minimized to point where new data lines will be displayed at the rate of approximately two lines per second. At this point it becomes obvious that a page erase after every line is not a desirable mode of operation. The use of multiple page erasures in rapid succession was judged to be more detremental to the user's analysis efforts than to have the most current line behind those less current. Partially offsetting this objection is the single line option. This option will, at user request display any line separately, thereby negating the effects of hidden line elimination for that data line.

The argument in favor of placing the most current line last becomes even more valid when one considers that the user has at his command sufficient control parameters to manipulate the display to suit his needs. Therefore, if hidden line elimination becomes a problem for him he may increase the absolute vertical spacing between each new data line, thus decreasing the effects. Or, he may decrease the degree of rotation of the display which will

increase the vertical line spacing, or finally he may decrease the amplitude of the display. With these controls available either individually or in any desired combination, the user may decrease the hidden line elimination effects to almost nothing. Thereby removing the major argument against the option of placing the most recent line at the rear of the display.

The new data rate of one line every two seconds, or possibly faster, which was mentioned previously assumes of course that the user desires new data as rapidly as is possible. This rapid data flow was in fact one of the design paramenters in that the processing of data was implemented in such a manner as to minimize all time factors possible. Thus, since the SPD program will display data as rapidly as it is made available, then the time factors are potentially much smaller than in a real time system. If the SPD method of display were to be implemented in a real time system however, these time delays might not be a problem. This factor for a real time system would be further reduced if the SPD display were to be utilized only when an area of interest had been located by another means, for example a normal gram analysis. At such time the SPD display could be used to provide an easier, more detailed and more reliable analysis of the data.

In such a real time application there would not necessarily be a Fourier processor in the system to increase system expenses. The only requirement placed on the installation by SPD is that the data be presented in digital form where its magnitude is directly proportional to the amplitude of the original signal. Therefore, the terminal could serve as an auxiliary display and analysis medium to augment already existing equipment, e.g. the gram writer. Such an implementation could prove beneficial in such equipment as the P-3C if suitable hardware changes were made to enable already existing CRT displays to process and display in SPD format.

A simpler installation would be on board an aircraft carrier for analysis of data returned by the S-3 ASW aircraft. However, this might entail the installation of a mini computer as well as a display terminal in order to provide the required display processing. This requirement would need to be assessed on an installation to installation basis as to what equipment was already in place and what it was capable of in the way of processing speed and memory size. The major disadvantage related to the lack of selective erasure is that if the need arises to change a portion of a given display the entire screen must be erased. An action which requires that the entire display be redrawn, repeating whatever data which the user might have desired from the previous page. The main difficulty here is that the programmer must attempt to decide during

the design phase what data the user will desire to retain and have the program retain it automatically. Alternatively, the user may be given the capability to interactively determine what will be retained from page to page, logically an easier solution to program, but one which would require memory to store every transaction. A memory requirement which could easily grow out of control if not somewhat restricted. In the SPD package the later approach was adopted to some degree. The user is given the alternative to specify at any time during program execution the number of data lines to retain from data page to data page. The default value here is zero and is never changed unless the user specifically requests it. All other data carry-over is eliminated with the exception of the process description variables printed at the bottom of each page. The user is given no option in this case, thus providing the limit on memory storage required.

Another feature added to aid the user in overcoming the disadvantage of the placement of the most current line was the use of a variable sideline capability. This feature is variable in that the user may specify by time relative to the beginning of the record, the line which he desires to see displayed in single line mode. Thus allowing the user a comparison between the currently displayed lines and any previous line which is stored on the disk memory. For the Control Data disk units this capability should cover all data processed from a single tape.

By virtue of its design principles the DVST has rather limited refresh capabilities, if in fact the particular system in mind has this capability at all. Without the existance of either refresh or selective erase capabilities it is very difficult indeed to show any type of dynamic display data. For the signal processing application this need for dynamic display is admittedly lower than in a graphics design application or a dynamic monitoring system but for the use in spotlighting the need is present for a refresh scan type of capability. Whether this is an emulation of a capability utilizing the normal scan circuitry or a special characteristic utilizing a different mode of terminal operation is insignificant. So long as the data can in fact be refreshed often enough to maintain a flicker-free, spotlighted image.

The TEKTRONIX/4014-1 terminal maintains a specific capability for the refresh operation labeled the write-thru mode. This feature provides the user with the option of displaying a non-storage, refreshed image which appears at significantly lower intensity than the store mode data. This feature, while it may perform acceptably for a new image which is not desired for maintainance, was found to be unsatisfactory for use in a spotlight operation. This was due to the lack of increased intensity present when a write-thru capability was used to write on top of a stored image. Consequently, the operation mode utilized was the storage type which provided sufficient intensity for

spotlighting, although at a slightly slower writing rate.

Thus, the disadvantages of the DVST format can signig-icant or insignificant depending on the application under consideration. In the instance of SPD the disadvantage related to the intensity of refresh was resolved by using the storage draw mode to emphasize the image. The problem related to data transmission rates was resolved to as great an extent as possible, but even more rapid rates are needed if the full capability of SPD is to be realized. However, no such solution was found for the problem derived from displaying the most current line in the back of the image. The emphasis concerning the disadvantages of the DVST is that it remains the basic responsibility of the end user to determine the impact of these problems for his particular application. And from this analysis make a reasonable decision based on the trade-off which is acceptable for a cost vs. performance evaluation.

D. ADVANTAGES OF THE DVST IN SPD

The most obvious and important of the individual advantages of the DVST implementation is the total lack of refresh requirements for image maintenance. The reasons for this were mentioned in the INTRODUCTION during the discussion of the DVST's physical construction and will not be repeated except to note that it is a significant advantage. From this lack of refresh requirements several other smaller but equally important advantages are gained,

advantages such as:

a. decreased processing requirements;

b. decreased memory requirements;

c. decreased system costs; and

d. limitless display complexity.

While all of these advantages are significant, the end result of their combination is even more so when planning an installation. That is, by combining the lower CPU requirements with the lower expense of the DVST display, the result is a much lower total cost for the basic system as compared to a system using a conventional CRT display. Therefore, if additional funds are still available, they may be utilized to otherwise up-grade system processing and storage capabilities as appropriate for the task under consideration. In order to adequately justify the previously memtioned advantages of the DVST a discussion of the details behind each area is provided.

1. Decreased processing requirements

As mentioned earlier, the CPU is not required to maintain the refresh requirements of the display as in the conventional CRT display. This advantage is not particular to the DVST approach however, since there are some other approaches which provide this same capability while utilizing the conventional CRT display. One method is the stand alone concept which provides the terminal with its own processor and memory. This is, in fact the method

followed in the original SPOTLIGHT implementation. The terminal's processor and memory may then to be used to alleviate the CPU from the refresh requirements thus freeing it for other processing tasks. While this approach does suffice to eliminate the heavy load of refresh processing on the CPU, it adds another processor and memory installation to the overall system costs. A cost versus performance trade-off which will increase system purchase and maintenance costs, the only question left unanswered is how much the increase will be.

Another option is to have the main processor perform all processing necessary to establish the desired display list, as required in the previous alternative, and then store the list in direct access memory. Upon the completion of the required processing and storage the terminal is passed the initial address of the display list in memory and can begin its own direct memory access. Thus, the terminal may provide the initial display and provide all necessary refresh requirements itself without interaction with the CPU. If the terminal is then provided with the additional hardware to perform actual display list modifications, there is an extremely capable, although expensive terminal system available for use. The only additional hardware expense of this system as compared to the DVST concept, without considering the cost of the terminals themselves, is for the additional memory required to maintain the display lists. This approach is the one

used for example, by the Vector General [18] graphics terminal and does provide very impressive capabilities which can never be realized on the current DVST technology. Capabilities which are particularly obvious in the areas of dynamic, three dimensional graphics where intensity modulation and display rotation can be effected internally to the terminal when properly initiated.

However, even with all of these advantages, the fact still remains that the DVST approach, as realized by the TEKTRONIX/4014-1, is several times less expensive than either of the previously mentioned approaches. Additionally, many of the capabilities provided by the Vector General approach are not necessary for the SPD environment and as such unnecessarily expensive. The main advantage of freeing the CPU from display refresh requirements is met by all of the solutions mentioned, however the DVST additionally removes the constant need of reserved memory for display list maintenance.

2. Smaller memory requirements

This advantage was mentioned previously and as such its discussion here will be abbreviated somewhat. The primary point for consideration here is that while all of the approaches mentioned in the section of decreased CPU requirements must build display lists, the specifics concerning the lists vary widely. In terms of size the lists for both the stand-alone concept and the display to direct memory access approach requires the display list

for the entire image be stored contiguously. The two approaches differ only in where the lists are stored and how they are accessed, both areas which were previously discussed. Thus, the actual memory requirements for a given display image will remain basically the same for the two except that the stand-alone requires an entirely separate memory unit.

At this point the DVST offers an easily distinguishable advantage, although with it is associated an equally valid disadvantage. When utilizing the DVST one need provide only a given segment of the total image as a display list at any time. Thus, as in SPD, one entire data line may have all display information calculated, placed in a buffer, and then displayed. Once the display process has been completed for this line the buffer is freed for the same process to take place on the next display line. Therefore, in the SPD system, for just the data lines themselves, with no clarification data displayed, the DVST will require memory for only one data line. Compare this to the alternatives which would require continual memory allocation for up to the maximum of twenty display lines. Additionally, for textual data the same buffer will be re-used in the DVST application, whereas for the alternatives additional memory would be required for this feature.

But now for the disadvantage. Since the DVST as implemented in SPD destroys all display data for the previous entries when preparing the display lists for the current entry, any screen modification of the current image requires the total erasure and recalculation and re-display of the entire page. This can be a disadvantage for some applications where the need for dynamic image rotation for example, is required. A significant limitation when compared to some equipment which can perform such modifications internally without any direct CPU intervention.

3. Lower system costs

Two areas are covered in this section, the costs of the CPU with its associated memory, and the cost of the actual display with its associated equipment. The decreased CPU and memory costs were adequately established in the previous section and derive, once again from the lack of refresh requirements. One area which has not been established however, is the cost of the terminal itself.

In addition to the CPU and memory capabilities required by the refresh technology, there is also a premium placed on the actual vector drawing rate capabilities of the CRT. Assuming that data can be provided suitably fast, the CRT with its associated equipment must be able to execute the display list as provided by the CPU fast enough to provide for flicker free operation. This speed will normally be on the order of 30-40 times a second but

varies with the particular phospher being utilized by the CRT. This speed of operation by the terminal directly affects the amount of data which may be displayed at any time, thus the need for maximum processing rates by the terminal. In order to increase the amount of data displayed the electronic capabilities of the terminal to receive and process the data must be improved, or the persistance of the phosphers increased or both.

Of these two alternatives the latter is preferable from a cost point of view. However, if the persistance is increased enough to significantly affect the required refresh frequency, then there would be an obvious blur left when an image was moved. This is not an acceptable solution for a dynamic application. Consequently, the only solution remaining is to improve the terminal's capability for rapidly processing data or increase the drawing speed of the display if that is the limitation. Either proposition may prove to be expensive, particulary if the display is already close to the state of the art.

Conversely the DVST is not restricted by these limitations for its basic operation mode since it draws each line one time for each new display page generated. Therefore, no distinct premium is placed on achieving the fastest possible drawing of data processing times other than that which is easily accomplished. Consequently, since the need to attempt to push the state of the art for refresh purposes does not exist, the DVST can be produced

for much less than can the conventional refresh CRT terminal. Additionally, since there is no concern over the amount of data displayed and the resulting possibilities for display flicker, the operator may display as much textual data for claraification as he desires. as he desires.

With respect to refresh, however, the SPD environment does create a special concern for the DVST approach since the need to selectively spotlight given images does exist. This particular area did result in some difficulties initially but with sufficient processing and interactively variable parameters (such as the number of lines to spotlight) the TEKTRONIX/4014-1 was found suitable in this respect. However, as mentioned before, any improvements in the terminal's refresh capabilities would increase its usefulness. The difficulty is that the TEKTRONIX/4014-1 is close to the state of the art, with respect to DVST technology, and further improvements are likely to prove expensive.

4. Limitless display complexity

The area of display complexity as mentioned breifly earlier, requires careful consideration and planning during the display design phase. Since there are no problems with flicker to cause concern, the display may easily become too complex to be useful unless specific attention is given to minimize the data displayed by the program. While this poses no hardware difficulties, it can easily

render the display useless for the human operator. Of particular concern here is the amount of data displayed during interactive processing and computer to user prompts. The area to be optimized is the total text displayed at any given time and several approaches may be utilized. One method is to eliminate terminal echoing of user originated commands, a method easily implemented on the TEKTRONIX but not chosen due to the need for the user to observe his input command, particularly in the event of an input error.

Another method is to minimize program prompts to the user, both in number and individual size. This method was the one chosen for SPD as the one most effective for user implementation. Additionally, the operator may command a clean reproduction of the current display, without the command history, spotlight frequencies or sideline characteristics of the current page simply through the normal command mode.

Yet another approach to minimizing the complexity of the display was to provide all textual data in the refresh mode. However, for reasons mentioned earlier in this thesis, this mode was not chosen. To review these reasons; in order to maintain the refresh presentation the processor must devote itself to continually refreshing the image. Thus, the total time to process a user request would increase since processing time is required to access and transmit the display data. Additionally, the character

generator for the TEKTRONIX terminal is limited to a speed of 4000 characters per second. While this speed is not so slow as to prevent the display of a single user command, it could be too slow to provide a display of an instruction sequence.

This establishes the major advantages of the DVST format in a general applications sense. It is necessary to determine the advantages and disadvantages affecting the implementation under consideration during the initial planning stages. Then a decision must be made to determine the result of cost versus performance trade-offs and if these will significantly detract from the installation's effectiveness. This approach must be utilized in order to determine the best technology for the proposed application. There is no complete, final answer which will always provide the best answer. Rather it must be approached on an application to application basis with consideration to the currently available technologies.

V. CONCLUSIONS

In general it was demonstrated that for the signal processing environment the DVST approach, as realized in the TEKTRONIX/4014-1 display terminal can be successfully utilized. With this utilization there are some limitations as well as some benefits to be gained, all of which have been discussed within the body of this thesis. For reiteration the prime disadvantages revolve around the loss of immediate, dynamically changing displays and some spotlighting limitations. The advantages are the smaller physical size, lower system complexity and system implementation costs. For the SPD application it was found that the advantages overcame the disadvantages.

As to the final display, the observations concerning overall performance were that the display was faster than expected, the greatest delays involving accessing data from tape or disk, as expected. The display was pleasing to the user due to the lack of display ficker, jitter, and the very fine line resolution (remembering that due to the application requirements, a image is not displayed long enough to make fogging a problem). Additionally, at any time the user may request and display as much clarifying data as desired without concern to flicker problems.

With respect to the CPU process loading requirements the programs, without including the spotlight mode, seem to cause few system loading problems. The conclusions concerning system loading are based on the effects on other users on the time sharing system which SPD utilized. If the spotlight mode of operation was not used other users noted little, if any degradation in system response to their requests. However, if the spotlight operation is in effect, the system loading substantially increases and while it does not prevent other users from working, it does slow their processing down significantly. At the same time however, the time sharing concept does interrupt refresh and requires single user priority to provide flicker free operation. This is only a factor in a time sharing installation. If the concept were implemented in a non-time sharing environment the single user requirement would not be an area of concern.

On reconsideration of the efforts leading up to the completion of this thesis a few points come up for review and indicate areas where a different approach would have been appropriate. Initially efforts were made to translate and implement the TEKTRONIX supplied PLOT-10 graphics software package from its standard FORTRAN form into the system language used at NPS. This area of endeavor was terminated prior to its completion for several reasons, the primary one being that while the software provided an impressive level of terminal capabilities,

very few of them were applicable to the SPD environment. As such the benefits to be gained did not warrant the time and hardware, primarily high memory requirements for the PLOT-10 package, needed to complete the translation and actual implementation.

Additionally, the initial system plans called for the utilization of both available PDP-11/50 processors, one for display control and one for controlling and storing the Fourier transforms as calculated by the CSP processor. With the system as currently implemented, only one PDP-11/50 processor is being utilized and the need for both processors has not been realized. This conclusion has been reconfirmed by the operation of the SPD package successfully in a time sharing environment. However, at this point one further modification to the initial plan is necessary. The need exists for the time-sharing environment at least, to enable the SPD routines to disable all other processes for the duration of the spotlight process if a flicker-free capability is to be realized. This lock-out of other processes need not be accomplished at any other time during execution, but for spotlighting evolutions it must be accomplished. The requirement for this is primarily due to the TEKTRONIX not maintaining either its own memory for the display lists or a direct memory access for display. The need for this lock-out of other processes was observed during final evaluation of the system and has not been implemented in SPD. The capability

to accomplish this has been met within the system however, through a Real Time processing capability which may be invoked at compile time. At the present time the Real Time capability exists only on the second PDP-11 processor. Consequently, since the SPD implementation was required to exist on the main processor due to early hardware restrictions the Real Time call does not exist for SPD at this time.

Finally, the TEKTRONIX/4014-1 is a very useful, easily implemented display medium for the SPD application. Its usefulness derives from its low costs in the areas of both hardware and software requirements for implementation. The implementation of the terminal should not be attempted however, until such time as the user has obtained the fastest possible interface equipment for both the CPU and the TERMINAL side of the problem. The minimum useable data transmission rate for acceptable refresh capability was found to be on the order of 154K baud and was obtained with a serial interface, however a parallel interface is available and its use should be investigated. Similarly, use of the available manufacturer's software is not recommended for the SPD application primarily due to the overhead required for its use and the simplicity of the software required to utilize the terminal in the graph mode. This overhead required for the manufacturer's software was realized in terms of the memory required to store it as well as the time required to modify it to

operate in the PDP-11/50 environment.

Thus, with the above the end result of this evaluation was that the TEKTRONIX/4014-1 DVST type of display provides a useful and relatively inexpensive display medium for graphical display of signal processing data. Useful in terms of purchase costs, both for hardware and software, and user effectiveness. The flash required for screen erasure was not found to be disagreeable, although its detremental effects are more significant in a darker room. In general it is a pleasing and simple display system to use for both graphical and alpha-numeric applications.

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